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# Digital orthophotos and GIS: the perfect couple

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## ABSTRACT

There are many definitions of GIS - what it is, and what it is not. Two main characteristics are shared by most of the modern GIS systems (both raster and vector oriented): first, the database's data structure featuring interrelated twodimensional tabular data and "geographical" data, and secondly the manipulation tools on geocoded data and associated attributes. This leads us to the well-known layer model. The layer concept is similar to other models of remote sensing, digital cartography, and graphic art databases, as well as to the recently developed softcopy concept. This coincidence is certainly not an accident.
Digital orthophotos belong to one of these layers, and they have a high potential for controlled GIS data manipulation. Digital orthophotos are not just a new GIS layer, but a GIS "partner". By coupling digital orthophotos to GIS, GIS data is put alive and data coherence is preserved at all stages. Coupling digital orthophoto data with GIS offers new perspectives for automatic raster, line and DEM information extraction, especially for softcopy purposes.
An overview of typical properties and advantages of digital orthophoto data is clarified and illustrated with practical results from environmental studies on different scales.


## 1. INTRODUCTION

The demand of raster and vector data users for image files, especially digital orthophotos, has spectacularly increased. Thanks to the development of fast workstations, the integration of images in cartographic processing is fully operational for the large group of GIS users. On the other side, those users are also requesting a diversity of output facilities for high quality image output and precise planimetric documents. Hardcopy and softcopy products must fit the highest quality standards before replacing the more traditional (analogue, photographic) products.
Image processing becomes more and more integrated in the different cartographic production steps, from softcopy photogrammetry via computer assisted photointerpretation up to non-impact printing. This paper concentrates on the role of digital image processing of remote sensing data for mapping and GIS purposes, and especially on digital orthophotos.
Remote sensing techniques deliver basic mapping data in raster format. Data acquisition is performed using different types of sensors installed on specific platforms. In the beginning, remote sensing focused on gatthering specific thematic information on the earth's surface, using specific spectral band selections. Today's spaceborne and airborne remote sensing techniques offer images for orthophoto production at various scales. Of these, aerial photography, using high resolution film, provides the most detailed information in the visible and near infrared wavelengths. After scanning, the data is ready for processing like any other comparable remote sensing data set. Aerial photography allows the user to prepare and select optimal conditions for data acquisition. High resolution scanning converts the photographic document into a digital raster file for digital orthophoto production.

## 2. DIGITAL ORTHOPHOTO PRODUCTION

In 1972, Eurosense started producing analogue orthophotos using an orthophoto projector for rectification of transparent film visual material. A large number of intermediate photographic and reprographic steps were necessary for map production. It became clear that the production speed could be raised and the image quality improved for both colour and black and white orthophotos

using image processing techniques. Other problems related to optical mechanical processing (such as correction of steep slopes) could be solved using digital processing, too.
In 1986, Eurosense started the development and integration of the different digital orthophoto production steps in the EUDICORT® software (Eurosense Digital Cartographic Orthophoto system). Several thousands of orthophotos at different resolutions and scales have already been produced using the EUDICORT® system. Digital orthophoto production by means of EUDICORT® includes 5 main steps:

### 2.1. Aerial Photography

Global Positioning Systems (GPS) are used for navigation and precise location of the aircraft. The metric cameras are equipped with FMC (Forward Motion Compensation) to obtain sharp photographs on black and white, colour and colour infrared film, even at low altitudes. An appropriate focal length of 30, 21 or 15 cm is chosen with respect to the flight conditions, the perspective distortions and the available elevation model. The FMC device allows elimination of the image motion in the flight direction. Moreover, a large aperture (f/4) allows a reduction of the exposure time and thus of the image motion due to the remaining movements of the aircraft (roll, pitch and yaw). The scale of the aerial photograph will depend on the required resolution of the orthophoto data. The scale of the orthophoto can vary between 1:500 and 1:50 000, corresponding to a resolution of the final raster data at ground level between 5 cm and 5 m.

### 2.2. Scanning

Photographic documents are transferred to digital data files by scanning at a specific resolution. Resolutions up to a few microns can be selected to scan the photo, including fiducial marks. Mostly, a resolution between 15 and 40 microns is selected for orthophoto production. An output resolution of at least 10 pixels/mm will be required for hardcopy reproduction of the final orthophoto product.

### 2.3. Geometric Correction

A digital orthophoto is an image that has been digitally corrected to remove any distortion due to tilt and terrain relief (the topographic surface). For a central projection, the camera position and tilt angles are computed from the collinear equations (or Newton equations) using a set of well-defined control points:

$$\begin{bmatrix} X - X_0 \\ Y - Y_0 \\ Z - Z_0 \end{bmatrix} = \frac{1}{f} \times M \begin{bmatrix} x - x_0 \\ y - y_0 \\ 1 \end{bmatrix}$$

with:

| | |
|---|---|
| $X_0, Y_0, Z_0$ | = camera position |
| M | = tilt angle matrix |
| f | = focal length |
| $x_0, y_0$ | = image perspective centre |

Aerotriangulation, with digital cross-correlation techniques, diminishes the processing time and improves the accuracy for depicting sufficient ground control points.
A digital elevation model (DEM) must correct the image distortions caused by the relief of the area. Digital elevation models are obtained by interactive or automatic correlation, by photogrammetric plotting from stereo pairs or from an existing database of the area. The geometric accuracy of an orthophoto will depend mainly on the precision of the DEM used. From projective equations, it can be deduced that the use of larger focal lengths can guarantee the same accuracy with less precise DEM.
After checking the accuracy, the orthographic position of each pixel is calculated. The orthophoto rectification or the so-called differential rectification process is performed using the indirect method (input coordinate to output coordinate image). Any rectangular grid in the output image becomes a trapezium in the input image. This method is equivalent to building a Geometric Deformation Model (GDM). The projective equations used for the DEM generate the GDM. The GDM step is important in the context of:

- orthophoto versus orthoimage definition
- the refraction index (as water refraction index)
- other camera geometry.

From a GIS point of view, DEM and GDM may be crossed by natural and artificial breaklines, specific area properties, etc.
The scanned data is finally resampled to a geometrically corrected image using bicubic convolution interpolations. Accuracy tests executed on digital orthophotos at different scales indicate that normally an RMS error of 1 pixel is obtained after differential rectification.

## 2.4. Radiometric Correction

In the past, one of the main criticisms against (analogue) orthophoto products was their lack of homogeneity, inducing interpretation problems. With digital images, radiometric processing has become easier and more controllable. The radiometric correction step has two objectives:

1. to get rid of colour discontinuities between neighbouring orthophotos;
2. to create a homogeneous colour representation in a large geographic area, necessary to produce image mosaics.

In aerial photography, 5 physical parameters contribute to colour variations:

1. the viewpoint
2. the illumination direction
3. the focal distance
4. the atmospheric conditions
5. the reflectance of different topographic entities (sun spots).

For these reasons, a physical radiometric correction model is unfeasible.
At the conversion into a digital data format, the scanner settings affect the image quality. High-end scanners offering a wide spectrum of selective colour corrections and individual LUT manipulations avoid loss of information.
For the radiometric correction algorithm, low-level image processing techniques (which do not have any relation to interpretation) such as contrast enhancement, LUT transformations, histogram

manipulations, etc. are applied. Calibration is based on the Helmholtz hypothesis for colour constancy (in the visible and infrared spectrum) to eliminate the differences in lighting conditions. Referring to mathematical morphology, the radiometric problem is a dimensional problem

- identical to the pixel location (location is expressed with units)
- the radiometry is a physically identical problem.

For pixels, references are available (i.e. control points). For radiometry, references are needed too, and one of the best calibration parameters is a functional of histograms.
Radiometric correction of the data takes a large amount of processing time, but enormously improves the image quality. Only after radiometric calibration, the user will obtain a homogeneous orthophoto coverage, necessary for mosaicking.

### 2.5 Mosaicking

Each orthophoto is produced with a certain degree of overlap with the neighbouring orthophotos. The preceding step of radiometric correction eliminates colour balance differences, although others may appear, such as:

- differences in the shadow orientation (i.e. for woods, buildings)
- phenological differences if photos are taken in different seasons or years
- small geometric discontinuities, as for bridges and buildings, related to parallax effects. Remember that the digital terrain model is defined for the topographic surface and does not take account of the heights of bridges, buildings, etc.
- reflectance differences in water, etc.

In this phase of processing, only the overlap area between two orthophotos is considered. The area in common is centred with respect to the real common border. This step is an interactive process in which a cutting trajectory between neighbours is defined, so that only the respective part of one of the two orthophotos is kept for the database. This

- minimizes the visual effects of parallax
- minimizes the visual effects of shadows
- realizes an homogeneous representation in case of differences in phenology
- prevents feathering between images.

## 3. DIGITAL ORTHOPHOTO PROPERTIES

### 3.1. Digital Orthophotos are Geocoded

Digital orthophotos offer at least the same precision as a line map (topographic map). Each pixel has a clearly determined position in a reference grid (e.g. Lambert grid).

### 3.2. Digital Orthophotos are Colour-Calibrated

By means of the radiometric and mosaicking modules two or more orthophotos can be merged to produce one homogeneous colour image of a higher quality than the original aerial photography.

### 3.3. Digital Orthophotos are Multitemporal

Photoflights over large areas may be interrupted due to changing weather conditions. Waiting periods of two to three months are not unusual, which implies important changes in lighting conditions and vegetation phenology. Digital orthophotography allows for the production of homogeneous documents without the dramatic colour discontinuities resulting from classic production methods. Thanks to this quality, digital orthophotos can be used for quickly updating existing maps.

### 3.4. Digital Orthophotos are Multiscale

As it is possible to merge two digital orthophotos, also a set of digital orthophotos (e.g. all 1:10,000 orthophotos covering a 1:25,000 or 1:50,000 map sheet) can be merged without radiometric discontinuities. Subsampling of digital orthophotos is also allowed.

### 3.5. Digital Orthophotos are Multispectral

As digital orthophotos are raster images, it is possible to apply classification techniques to colour and colour infrared pictures. Multitemporal, multiscale and multispectral properties are exclusive to digital orthophotos. They do not exist with analogue documents.

### 3.6. Digital Orthophotos are Remote Sensing Compatible

Thanks to its multiscale and multispectral properties a digital orthophoto can be compared to remote sensing data (e.g. from Landsat TM) to complete the interpretation process with other multispectral channels. This is yet another important argument in favour of digital orthophoto usage.

Remote sensing data can be used as a reference to update or complete GIS data. Many theoretical and practical studies have been published on this subject. All come to the conclusion that digital colour orthophotos offer a high degree of mapping accuracy as well as a high degree of image detail necessary for map updating. The combination of GIS and digital orthophotos will be discussed extensively in the next chapter.

### 3.7. Digital Orthophotos are Overprintable

Overprinting digital orthophotos with existing line or thematic maps provides highly detailed documents giving a clear overview of the situation. According to the United States Geological Survey, this property may reduce the need for costly field work.

### 3.8. Digital Orthophotos allow Quantitative Calculations

Digital orthophoto data can be used to carry out quantitative calculations, such as the calculation of surface areas, surface area differences, displacements, etc.

### 3.9. Digital Orthophotos are Fit for 3D Modelling

Digital orthophotos may be draped on a DEM for perspective viewing, often used for environmental studies. Stereo orthophotos are fully complementary to orthoimages and offer a new range of applications.

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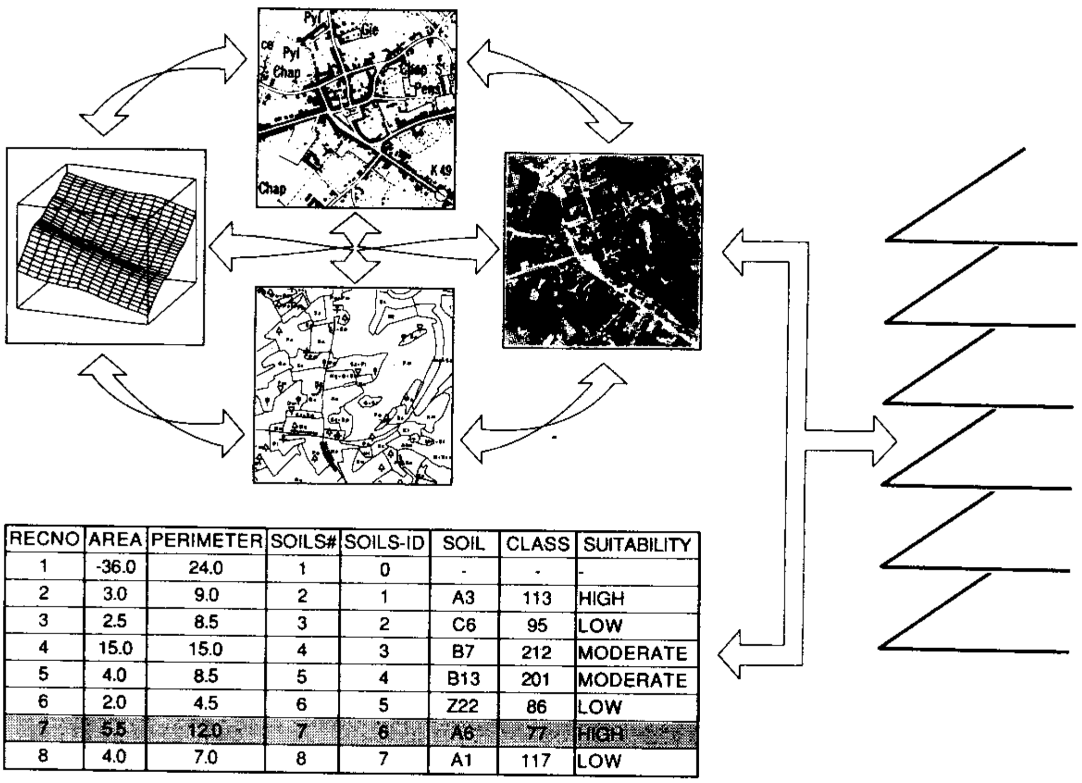
### 3.10. Digital Orthophotos are Multidisciplinary

Orthophotos are a basic data source and allow a wide range of GIS users to extract the requested information. By this, orthophotos are essentially complementary to other GIS coverages, offering mainly a specific thematic information in raster or vector format.
We should bear in mind that any interpretation activity is an irreversible process which puts all non-significant information in the background (in GIS this means an empty set of data). According to the so-called vision paradigm, the distinction between figure and background constitutes one of the fundamental problems of vision. Up to now, nobody has been able to find only one argument to destroy the paradigm. Inserting pre-interpreted data in a GIS therefore means deliberately cutting off other valuable information.
Looking at aerial photographs, interactions are discovered between different areas and complex relationships and between different kinds of land use. Our need for information increases. Between an aerial photograph and a digital orthophoto there is only a geocoding transformation, without loss of information. Unknown relationships ask for a multidisciplinary approach before decision-taking, interpretation; an idea which is of crucial importance.
Including thematic map data in an orthophoto is certainly one of the best ways to stress certain features without affecting the interpretation. Thanks to GIS tools offering the possibility to manipulate and model data, digital orthophotos become increasingly important as primary information suppliers.

## 4. DIGITAL ORTHOPHOTOS AND GIS: THE PERFECT COUPLE

### 4.1. Conceptual Discussion



| RECNO | AREA | PERIMETER | SOILS# | SOILS-ID | SOIL | CLASS | SUITABILITY |
|---|---|---|---|---|---|---|---|
| 1 | -36.0 | 24.0 | 1 | 0 | - | - | - |
| 2 | 3.0 | 9.0 | 2 | 1 | A3 | 113 | HIGH |
| 3 | 2.5 | 8.5 | 3 | 2 | C6 | 95 | LOW |
| 4 | 15.0 | 15.0 | 4 | 3 | B7 | 212 | MODERATE |
| 5 | 4.0 | 8.5 | 5 | 4 | B13 | 201 | MODERATE |
| 6 | 2.0 | 4.5 | 6 | 5 | Z22 | 86 | LOW |
| 7 | 5.5 | 12.0 | 7 | 6 | A6 | 77 | HIGH |
| 8 | 4.0 | 7.0 | 8 | 7 | A1 | 117 | LOW |

Figure 1.

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When GIS got widespread these last years, two questions arose: "what is a GIS" and "what is not a GIS". The number of answers is infinite. Whatever the definition of a true GIS, two main characteristics of both raster and vectorial GIS always turn up:

- The data base structure (relations between two-dimensional tables data structure).
- The manipulation tools on geocoded data and their associated attributes in the two-dimensional tables.

This leads to the model illustrated in Figure 1. The geometric data components are DEM, thematic, topographic and image data. Already a raster vector data representation is needed.
The layer model is not a specific GIS concept: the same model can be found in remote sensing, digital cartography and digital graphic art techniques as well as in the recently developed softcopy concept. This coincidence is certainly not accidental: it is a positive answer to a coherent space and priority management.
It seems only logic that digital orthophotos belong to one of these layers. But for what reasons? Let us first elaborate on two important points:

*1. Most GIS presently in use as a reference (a substitute of the base line maps) are still vectorially designed. Aerial photographs serve as a data source to these vectorial GIS - just as they do to digital orthophotos - but, unlike for digital orthophotos, they are not in raster mode.*

The use of vectorial data for GIS has a historical reason: survey and mapping techniques were based on geometry and trigonometry, implying the use of vectors. Therefore, vectors have always been the common way of representing spatial phenomena. So, from a traditionalist point of view, the data collection is kept in a separate set of procedures and GIS are considered analogous to classical maps.
However, we have grown aware that the imposition of vectorial lines on a landscape is subjective and inexact. Vectors would be fine if reality could be defined as only lines and edges, which it cannot.
With the advent of high resolution raster technology, the classical step-by-step procedure applied to spatial data (photogrammetric plotting, CAD, GIS, cartography) is collapsing. What remains are the raster/vector components. The reason for this collapse is defined as softcopy. Softcopy makes a lot of the old questions become meaningless, such as for example: "Does information extraction belong to photogrammetry or to GIS techniques?", "Does crossing of information belong to GIS or to cartographic techniques?", "Is buffering specific to GIS or to cartographic symbolization?", "What remains specific to photogrammetry? And what remains specific to GIS?". The term softcopy refers to a representation of text, image, and symbol data in a digital form. Figure 2 illustrates the classical methodological steps from stereo images to a map. With softcopy, this step-by-step methodology fails.

*2. At the moment, after twenty years of electronic data gathering, people still digitize existing maps, thus creating GIS or pseudo-GIS data bases, while they collect spatial data on any kind of information system, on any kind of device and at a wide range of scales. To believe that they are building geographic reference systems is very often a big illusion. In fact they are probably establishing huge data cemeteries.*

It is time to make these data live again!

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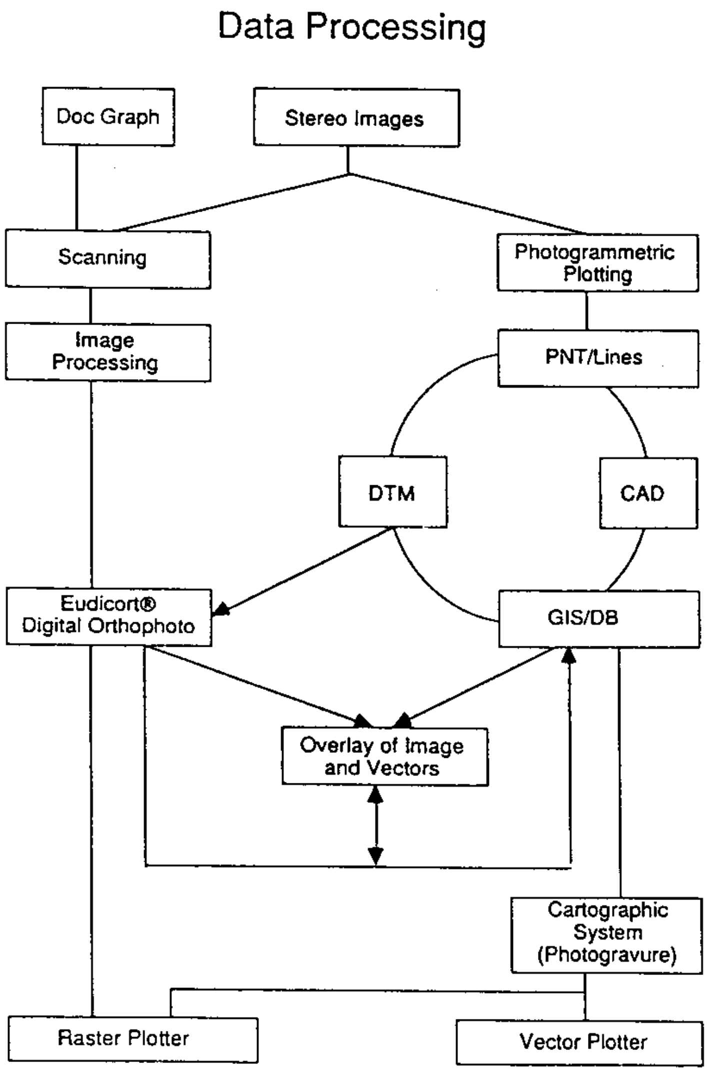


Figure 2.

### 4.2. Coupling of Digital Orthophotos and GIS

The digital orthophotos in a GIS are not just another GIS layer, but a real GIS partner as a reference layer. The combination can be illustrated by the scheme in Figure 3.
Metaphorically speaking, each partner will share his best qualities with the other, taking into account their respective individuality. Their union is based on 2 dynamic concepts: scaling and correlation.

#### 4.2.1. Scaling

It was already pointed out that digital orthophotos have a multiscaling property. This means that the forward and backward zooming factor can be controlled, which is equivalent to man's ability to have an overview or to focalise on details.
For a specific GIS (related to a particular scale or precision) the digital orthophoto will be zoomed down and then used as a geographic reference (Figure 4).

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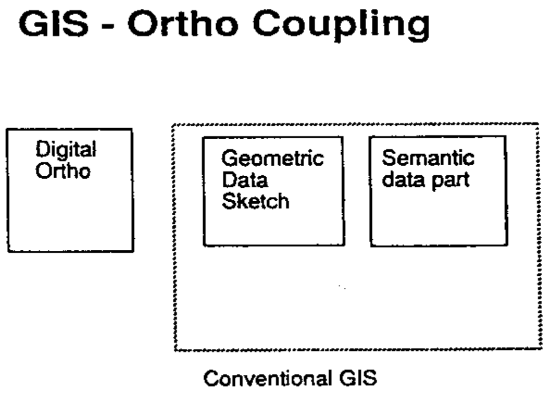


Figure 3.

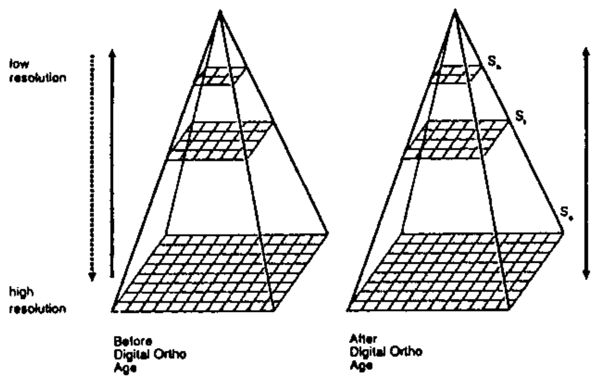


Figure 4.

Before the advent of digital orthophoto techniques, any scaling of low to high resolution was a conjecture. Now, up and down scaling is under control. The problem of scale incompatibility has thus vanished.

### 4.2.2. Correlation and Updating

One of the purposes of softcopy technique is to automatically extract a DEM from a digital stereo couple. To do so, the softcopy methodology adopted Marr's vision theory: it consists of first extracting the characteristic lines by edge detectors (Sobel, Zero crossing,...) in both images. The derived images are then called primary sketch images. The depth information is obtained by correlation algorithms in order to find the conjugated lines. An intensive use of hierarchical images (high/low resolution images) increases the performance of the correlation.

We propose to adapt this idea to the digital orthophoto-GIS couple. This GIS coordinate space part is now used as a primal sketch (in Marr's sense). Qualitatively speaking this is how our brain works when we have to find control points in sketch-based images - that is: when we have to find our way using a map. On the quantitative side, correlation measurements are allowed in digital images.

The updating process can be regarded as follows: if a correlation is found between a GIS graphic entity and the digital orthophoto, the graphic entity is snapped onto the corresponding orthophoto conjugated shape element. The coordinates of the graphic entity are updated to the digital orthophoto reference. The semantic data part remains unchanged. Figure 5 illustrates this process and is a synthesis of Figures 1 and 4.

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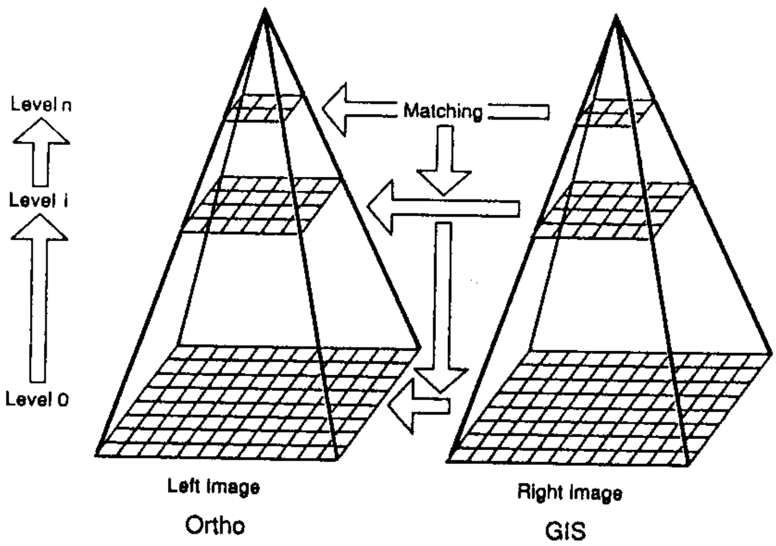


Figure 5.

This procedure is not just a theory. This is illustrated by comparing digital orthophotos with scanned line or thematic maps. A fully automatical process, however, could not be developed yet.

### 4.3. Digital Orthophoto Coupling Advantages

It is yet impossible to give an exhaustive list of all the advantages the coupling of digital orthophotos to a GIS may offer. The following evolutions may be expected:

1. To each correlated feature there is not just a geometrical snapping but also a direct link to the associated attributes. A recoding phase is not necessary. All existing scale-dependent data may be merged and selected to a unique reference (see Figure 1).
2. The GIS database integrator allows the GIS to be linked to non-graphical databases.
3. Up to now, incoherent or mutually incompatible scale-dependent GIS (precision limit) data can now be upscaled by means of the digital orthophoto's multiscale property.
4. GIS built from map documents containing map symbolisation and generalisation constraints may become useful at last.
5. Improved updating. At the moment nobody has any idea about the real cost for maintenance and updating of GIS data, nor about the methodology that is to be used for it. Sometimes it is easier to ignore future difficulties than to try and prevent them. It can be said that today's inflation of data acquisition will not simplify things for tomorrow. Today, GIS data are cut from their environment according to certain selection criteria and thematically oriented interpretation processes. GIS data lead a life of their own. They may follow a divergent evolutionary process, becoming completely isolated from and incompatible with the reality they were based on, all this because of a lack of feedback. Such data risk to become meaningless. There is no reason to believe that the present GIS will not meet the same problems as the cartographic production processes in the past did: after two or three information updates the data lost their meaning and a new phase of data acquisition was necessary. Contemporary GIS data acquisition and maintenance can be compared to the traditional cartographic production methodology. The soft-copy digital orthophoto component gives feedback information for data maintenance and updating and becomes a native data layer.

6. Modelling, new environmental knowledge, benefit of a coherent framework with orthophoto-GIS couple. This will serve a more multidisciplinary user group.
7. It is clear that image understanding techniques (= high level image processing) will lead to an increased development of automatic procedures. In the meantime, pragmatic solutions have to be found. These require a computer-assisted methodology with a high response time.

## 5. CONCLUSIONS

Before the use of digital orthophotos in GIS:

- there was no interaction between map users and the mapping process;
- map updating was a special occupation in itself;
- photogrammetrists were experts in the field of line mapping.

Now these tasks have eroded they are being substituted by specialized activities in the field of digital imagery. Users are now able to carry out queries in previously unavailable GIS information because of the previously missing image component (the orthophoto as a reference layer).
The digital orthophoto-to-GIS coupling has been designed:

- to reduce the life cycle of data processing;
- to support multidisciplinary teams tracking phenomena in a much faster decision process.

Eurosense's experience in combining digital orthophotos with GIS is confirmed by USGS experiments to update DLG (digital line graph) files. Orthophotos that are overprinted with existing line maps provide a highly detailed representation of map data requiring deletions, additions or modifications in the graphic map revision.
Digital colour orthophotos offer a high degree of image detail and constitute a better framework for environmental feature extraction as well as a more accurate data location for GIS updating. Digital colour orthophotos provide an ideal platform for raster/vector integration and for new multidisciplinary studies.
GIS and image understanding technology will improve continuously, thus reducing the probably high initial cost of GIS data maintenance.

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